Sludge Treatment in Reed Beds Systems – Development, design, experiences

Sludge treatment in reed bed systems is a thoroughly tested method. Experience shows that the method is an environmentally friendly and cost efficient sludge treatment

Author: Steen Nielsen

Abstract

There are important differences in the environmental perspectives and costs involved in mechanical sludge dewatering followed by disposal on agricultural land compared to reed bed sludge treatment. The effect on the environment of the operation of a Sludge Treatment in Reed Beds system is seen as quite limited compared to traditional sludge treatment systems such as mechanical dewatering and drying, with their accompanying use of chemicals; incineration; direct deposition on landfill sites, etc. After reduction, dewatering, and mineralisation in a reed bed sludge treatment system, sludge with a solids content of 0.5-3% can attain depending on the sludge quality dry solids content of up to 20-40%. In addition, mineralisation removes up to 25% of the organic matter in the sludge. The quality of the final product in sludge reed beds with respect to pathogen removal and mineralisation of hazardous organic compounds after treatment make it possible to recycle the biosolids to agriculture.

Loading - operational strategy

The operation of a reed bed system may be divided into a number of periods relating to the lifetime of the system. A system generally runs for a total of at least 30 years; this period is divided into two or three 8-12 year phases. Each phase consists of commissioning, normal loading, emptying and re-establishment of the system. Full Operation following the commissioning of the plant operations means that the yearly loading is increased to the sludge production from the wastewater treatment plant corresponding to the maximum capacity (tons dry solid/year) of the sludge reed bed system. The loading strategy involves assigning an individual quota to each individual basin. This quota is a sludge volume which generally increases throughout the entire period of operation until emptying, but it may also vary or even decrease to zero for periods. The length of the loading periods and rest periods between loadings depends on the age of the system/basin, the dry solid content, the thickness of the sludge residue and the intensity of partial loadings during the period of loading. On a daily basis, the basins are subjected to a loading of 1-3 partial loadings of approx. 1 hour for a short period (from a few days to a maximum of 2 weeks during commissioning) until the quota is used and loading switches to the next basin.

Mechanical sludge dewatering involves conditioning with chemicals, usually in connection with the dewatering process itself. Either organic polyelectrolytes or inorganic conditioning substances are used (Table 1). In a sludge reed bed system the dewatering process is governed

Key factors:

- Long-term experience (> 20 years) exists for Sludge Treatment Reed Bed Systems
- Operation is reliable and flexible, with very low operating costs, low energy consumption and no use of chemicals
- The areal loading rate is set to maximum 30 - 60 kg dry solid/m²/year after commissioning
- Regardless of sludge type and the size of sludge production, a minimum of 8 – 10 basins are necessary
- The basin depth must be no less than 1.7-1.8 m from the filter surface to the crown edge
- Beds are usually emptied every 8-10 years, a final dry solids content of 20 – 40 % can be achieved before emptying the beds.
- Experience shows that final sludge quality allows recycling the biosolids on agricultural land.

Table 1: Dry solid content related to dewatering method

Dewatering method	Centrifuge	Filter Belt Press	Filter Press	Traditional Sludge Bed	Sludge Reed Beds Systems
% Dry Solid (DS)	15-20	24 (15-20)	32	10	20 – 40

by the sludge quality, the climate, the wind, the gravity and the vegetation. The water in sludge with a dry solid content of 5% can be divided into pore water (66.7%), capillary water (25%), adsorption water and structurally bound water (8.3%). Dewatering the pore water concentrates the sludge to a dry solid content of about 15%. Further dewatering by removal of the capillary water concentrates the sludge up to a dry solid content of about 50%. The remainder of the water in the sludge may be removed by drying. Reed beds have been used for sludge reduction in Denmark and Europe since 1988 when the first sludge processing system was introduced. Long-term sludge reduction takes place in reed-planted basins, partly due to dewatering (draining, evapotranspiration) and partly due to mineralisation of the organic matter in the sludge. From waste-water treatment plants the sludge is pumped onto the basin surface/sludge residue. The dewatering phase thus results in the dry solid content of the sludge remaining on the basin surface as sludge residue, whereas the majority of its water content continues to flow vertically through the sludge residue and filter layer. The sludge residue water content is further reduced through evapotranspiration. In addition to dewatering, the organic matter in the sludge is mineralised, thereby minimising the sludge volume. The overall sludge volume reduction occurs without the use of chemicals and involves only a very low level of energy consumption for pumping sludge and reject water. Experience from the reference plants is that this type of system is capable of treating many types of sludge with a dry solid of approx. 0.5 to approx. 3-5%.

The system runs at full capacity for subsequent 10-year periods of operation, including periods of emptying. Normally, emptying is planned to start in year 8 and is completed in year 12 of each operation period. In order to meet the requirements of capacity for a 10-year treatment period of operation, as well as dewatering of the sludge residue to a dry matter content of approx. 20 - 40% depending on the sludge quality (Table 1), the following dimensioning standards are recommended. Dimensioning of the sludge reed bed systems is based on the following factors: Sludge production (tons of dry solid per year), sludge quality, sludge type and climate.

Sludge quality

The physical quality of the sludge changes at different stages of the dewatering process. The content of fat (max 5000 mg/kg DS) in the sludge, as well as the form of production (e.g. low sludge age, concentration, pre-dewatering using polymer, mesophile or thermophile digestion) are of importance to the sludge dewatering capacity and to the final dimensioning and number of basins. In addition to the sludge dewatering capacity, loss on ignition is a factor in the dimensioning. As a rule, a loss on ignition of 50-65% is recommended.

Areal loading rate

The areal loading rate is determined in relation to the sludge type, climate and must take emptying into account. With regard to loading of surplus activated sludge, the areal loading rate is set to maximum 30 - 60 kg dry solid/m²/year after commissioning. With regard to sludge types, e.g. from digesters (mesophile, thermophile), sludge with a high fat content, or sludge with a low sludge age (< 20 days), an area loading rate of maximum 30 - 50 kg DS/m²/year is recommended.

Number of basins

In relation to a 10-year period of operation, dewatering, vegetation and mineralisation, it is necessary to operate the basins with alternating periods of loading and resting. Regardless of sludge type and the size of sludge production, a minimum of 8 – 10 basins are necessary, in order to achieve the required ratio between loading and resting periods. Experience shows that systems with too few basins, i.e. fewer than 8, often run into operating problems, including very short periods of operation until emptying with poorly dewatered sludge residues and poor mineralisation. The basin depth must be no less than 1.70-1.80 m from the filter surface to the crown edge. The basins must have a sufficiently high freeboard to allow for 1.50-1.60 m of sludge residue accumulation. Basin capacity must also allow for increased loadings during the emptying phase of e.g. 2-4 years until all basins have been emptied.

Figure 1: Kolding Sludge Reed Bed System for 125000 PE (September 2000)

System description and design

Sludge from the wastewater treatment plant the sludge may be pumped out from the active sludge plant, final settling tanks, concentration tanks or digesters in batches into the basins.

Filter design and reeds

Each basin forms a unit consisting of a membrane, filter, sludge loading system and reject water and aeration system. (Figure 1). The total filter height is approx. 0.55 0.60 m before sludge loading. The reeds contribute to dewatering the sludge via increased evapotranspiration from the sludge residue and by mechanically influencing the sludge residue and filter. Finally, the presence of reeds contributes to the mineralisation of the organic solid in the sludge.

Sludge loading, reject water and aeration systems

Loading must be planned in such a way as not to inhibit development of the reeds and to prevent the sludge residue from growing so fast that the reeds cannot keep up horizontally and vertically. It is not recommended to apply a 100% loading rate immediately after planting. Pressure pipes are installed to each basin, terminating in a distribution system to distribute the sludge. An important detail is to ensure that the sludge is pumped out in a way which creates a uniform and even sludge load across the entire filter area. The reject water system has two functions. The first is to collect and return the filtered water to the wastewater treatment plant. The second function is to aerate the filter and the sludge residue.

Environmental impact assessment

Sludge treatment in reed bed systems is a thoroughly tested method with a number of proven advantages. Experience shows that the method is an environmentally friendly and cost efficient sludge treatment. It uses very little energy and no chemicals, has a minimum of CO_2-emissions, provides a good working environment, and reduces sludge residue significantly. The European Union Water Framework Directive (2000/60/EC) calling for cleaner discharges from our waste water treatment facilities can result in more sludge, due to the improved treatment; however, managing sludge is rather costly. In countries like Denmark, Germany, France, Spain and Sweden sludge treatment in Reed Bed Systems are a common and a well-proven method during the last 20-24 years (De Maeseneer, 1997, Giraldi et al., 2008; Lienard et al., 1995; Nielsen, 2003a, 2003b, 2008; Pempkowiak and Obarska-Pemkowiak, 2002; Obarska-Pemkowiak et al., 2003; Peruzzi et al., 2007; Troesch et al., 2008a, 2008b; Uggetti et al., 2009a, 2009b; Zwara and Obarska-Pemkowiak, 2000).

Better working environment

When the system is setup, there is no contact with the sludge. There is no noise from the system as there is from many other types of treatment systems, and there is no odour from it either. The system works effectively to reduce pathogenic bacteria like Salmonella, Enterococci and E. coli, thus making it a lot safer to be on site.

A cost effective system

The man-hours needed to run the system are fewer than with traditional methods, and require only a weekly control-visit to the site of about one to two hours. Sludge treatment reed bed systems utilise the forces of nature to reduce and treat sludge. The only appreciable power consumption is by the pumps used to transport sludge and reject water. This means that the reed bed system uses much less power than other systems. Transport costs will be reduced substantially, while the volume of sludge can be reduced to approximately 1.5-2.5 % of its original volume. The sludge will be of a better quality and suited for use on agricultural land. This offers more opportunities for disposing of the sludge after treatment.

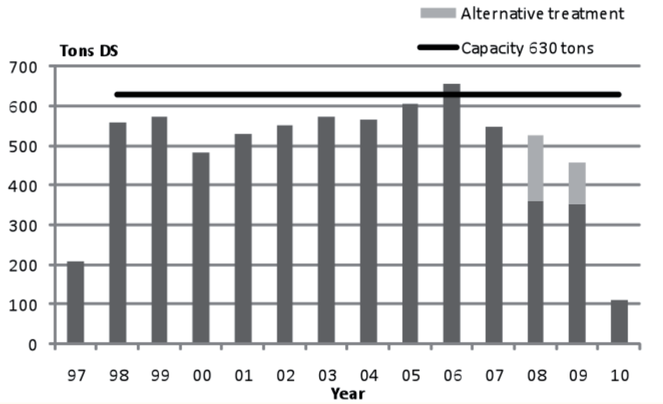
No chemicals needed

Sludge treatment in Reed Bed Systems uses no chemicals in the dewatering process. This means a considerable improvement in the working environment along with a reduction of the chemical residue in the treated waste water passing into the environment.

Good options for recycling

The content of substances in sludge that are foreign to the environment can be reduced to such a degree that the sludge conforms to the limits and norms for deposition on agricultural land. Treatment in a sludge reed bed system was shown to be effective at treating raw sludge containing large amounts of pathogenic bacteria including Salmonella, Enterococci and E. Coli. As a general rule, pathogenic bacteria that are excreted and end in an alien environment only live for a short period of time, depending upon various environmental factors and the bacteria's own characteristics.

The sludge (approximately 0.5-0.8% DS) loaded into the individual basins contained a large number of bacteria. Salmonella, Enterococci and E. Coli were found in the sludge in the following quantities: 10-300 per 100 g (wet weight), 7000 – 250000 CFU/g (wet weight) and 800 - 10000.10^3 CFU/100 g (wet weight), respectively. Analysis of the reduction in pathogens in the sludge residue through a period of 1-4 months after the last loading from the Helsinge sludge reed bed system (basin no. 8) indicated that the pathogen content was reduced to <2 per 100g (Salmonella), <10 CFU/g (Enterococci) and <200 number/100 g (E. Coli). For Enterococci and E. Coli the reduction was approximately log 5 and log 6-7, respectively (Nielsen, 2007).



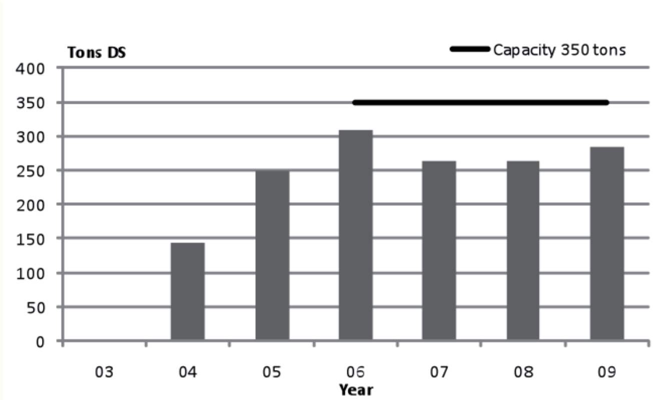


Figure 2: Sludge production and sludge load (left: Helsinge, right: Nordborg)

Mineralisation of Linear Alkylbenzene Sulphonates (LAS) and Nonylphenolethoxylates (NPE), which may be detrimental to the environment, if spread in large concentrations, in mesophilic digested sludge was observed during a 9 month monitoring programme. The reduction was 98% for LAS and 93% NPE. After the treatment of sludge, recycling options are good, particularly in agriculture. The sludge quality is cleaner and more adaptable in the natural cycle than mechanically dewatered sludge (Nielsen, 2005).

Case Studies

Experience from a large number of systems in many countries treating a whole range of sludge types has shown the efficiency of the method, which can be demonstrated in selected cases.

Helsinge sludge reed bed system

Sludge production from the Helsinge wastewater treatment plant (42000 PE) consists of activated sludge directly from the activated sludge plant and activated sludge from final settling tanks. This production (tons dry solids) constitutes approximately 66% of the loading of the sludge reed bed system. The remaining 33% of the sludge production consists of concentrated anaerobic activated sludge from 4 smaller wastewater treatment plants. The type of sludge was mixed in each delivery before being added to the reed bed system. The sludge was pumped via a mixing tank and a valve building, where the sludge flow and dry solids were registered before being led to the respective basins. Total sludge production has increased during the period from 1997-2005 from approx. 209 tons of dry solid annually to approx. 606 tons of dry solid annually. Annual sludge production amounts to 550 - 600 TDS (Figure 2, left).

The Helsinge Sludge Reed Bed System is a Danish system that was established in 1996 and consists of 10 basins, each having an area of 1050 m^2 at the filter surface. The system has a capacity of 630 TDS per year and a maximum area loading rate of 60 kg DS/m^2/year. The annual load rate (tons dry solids) of the Helsinge sludge reed bed system during the period from start of operations and to 2010 has been in the order of 90 % of capacity. From 2000 to 2005, loading has increased by approx. 130 tons dry solids. The loading regime of the system consists of applications of approximately 130-150 m^3 of sludge (mixed sludge) being applied once or twice daily to the plant's basins in relation to individual basins' loading quota and capacity, with the feed concentration being approximately. 0.5-0.8 % DS. Each basin was subjected to a loading quota of 1,500 m^3 over a period of approximately 6-8 days. Loading was followed by 45-65 rest days.

After commissioning the individual basins were subjected to an average loading rate of approximately 55-65 TDS per year, resulting in an average area-specific loading rate of 55-64kg DS/m^2/year. Because of the increasing sludge production and emptying of two basins yearly, the area-specific loading rate has increased from approximately 46 kg DS/m^2/year in 2000 to 68-88 kg DS/m^2/year in 2007. The sludge residue height status in basin 1 in relation to time and area-specific loading rate (kg dry solid/m^2/year) was calculated on the basis of scale pole readings. The sludge residue height increase from 1998 to 2005 was approx. 1.20 m (basin no. 1), and the total sludge residue height by April 2008 was approximately 1.60m (Figure 4). Helsinge sludge reed bed system has been emptied over a 4-year period (2005-2008), with 2-3 out of 10 basins selected for emptying per year. Capacity during the emptying period was maintained at 630 tons of dry solids per year. The last 3 basins were emptied in 2008.

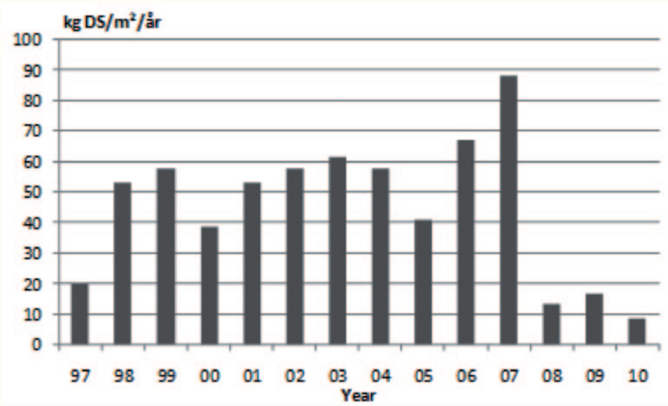


Figure 3 Helsinge Sludge Reed Bed System (basin no.1) Average area loading rate (kg DS/m^2/year)

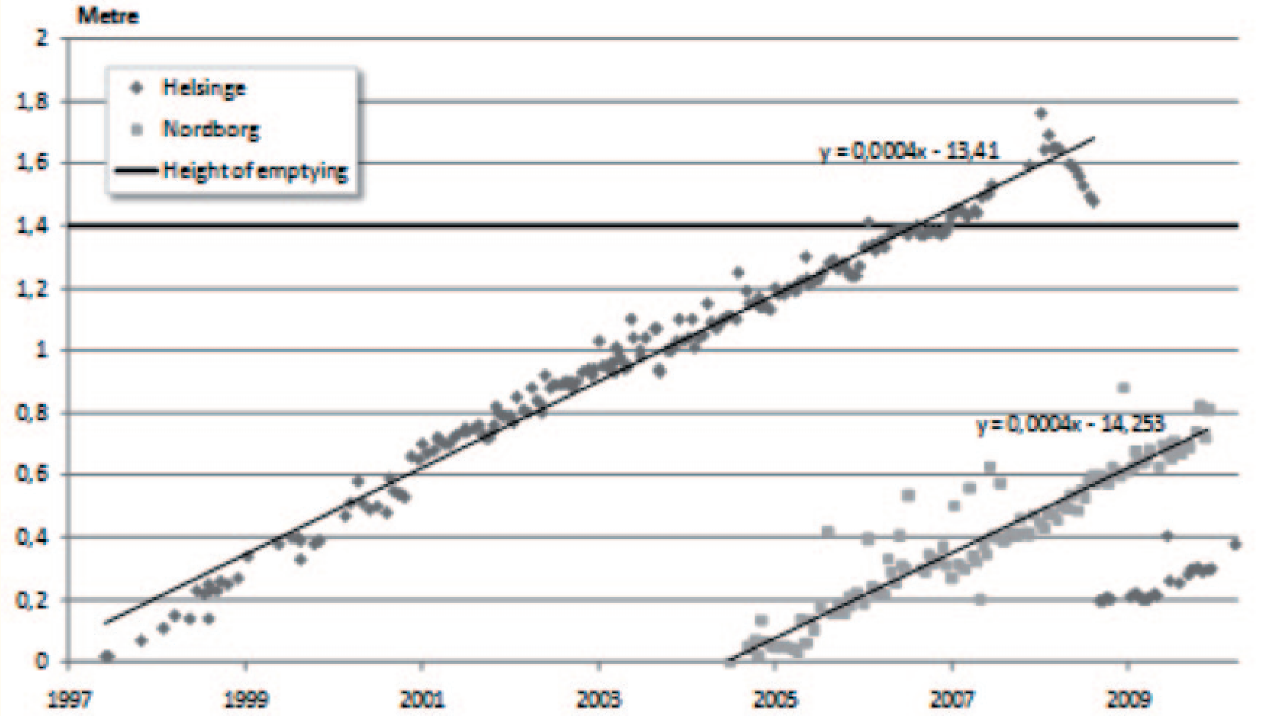


Figure 4 Sludge residue increment

Sludge residue quality

The quality of the sludge residue in the Helsinge sludge reed bed system met valid statutory order criteria with regard to heavy metals and hazardous organic compounds for use on agricultural land after ten years of biological treatment in the sludge reed bed system. The dry solids content in the sludge residue was up to 35.5%. Nitrogen and Phosphorus contents were on the order of 22-28 and 30 g/kg DS, respectively.

Emptying, Recycling and Regeneration

The plan was to empty the Helsinge over a 5-year period (2005-2008) with 2-3 out of 10 basins selected for emptying per year. The two basins selected for emptying are excluded from the loading plan approximately ½-1 year before emptying, and have a reduced load the first year after emptying. Capacity during the emptying period (5 years) was maintained at 630 tons of dry solids per year despite reduction of the basin number during the emptying period. The loading of individual basins increased from approximately 55 to 88 kg DS/m^2/year, as system loading during the emptying period applies to only 6-8 basins. From each of the basins approximately 1000-1400 tons of sludge residue were removed. The sludge residue was deposited on approx. 158-170 ha taking into consideration Phosphorus content with max. 90 kg P/ha for individual areas every third year. Maintaining full capacity during emptying is only possible provided that the basins are re-established after emptying with sufficient regeneration of vegetation, and provided that the loading rate is adapted to vegetation growth. Helsinge sludge reed bed system has generally had a satisfactory rate of regeneration after emptying in both 2005 and 2006, so that re-planting basins has only been necessary in few of the 10 basins.

Nordborg sludge reed bed system

Nordborg Sludge Reed Bed System (dimensioned to process wastewater from 18000 PE.) is another Danish system with 10 basins. The system was established with reeds in 2003 and has a capacity of 350 TDS per year. Each of the basins has an area of approx. 705 m^2 at the filter surface and a maximum area-loading rate of 50 kg DS/m^2/year. Sludge production from the WWTP consists of activated sludge (SAS) directly from the activated sludge plant and digested sludge from a mesophil digester. The two sludge types are mixed before being added to the Reed Bed System. 90 – 120 m^3 (approx. 0.5 % DS.) of SAS is mixed with 3-6 m^3 of digested sludge (approx. 2-3 % DS). The Annual sludge production amounts to 250 - 300 TDS (Figure 2, right).

Finally, the batch is diluted with effluent from the WWTP to a final volume of 140-160 m^3. The system's loading regime consists of applications of approximately 140-160 m^3 of sludge (approx. 0.6-08 % DS) once daily. From 2006 on, each basin was subjected to a loading quota of 600 m^3 over a period of approximately 4 days. Loading was followed by a 36-64 days' rest period. The area-specific loading rate was between 36-44 kg DS/m^2/year in period 2004 to 2009. The sludge residue height increased in the period from 2004 to 2009 by 0.83 m (Figure 4). The plan is to empty Nordborg sludge reed bed system over a 4-year period (2011 2014), with 2-3 out of 10 basins selected for emptying per year. Capacity during the emptying period will be maintained at 350 tons of dry

Figure 5 Nordborg Sludge Reed Bed Systems

Figure 6 Trials for Hanningfield Sludge Reed Bed Systems (June 2009)

solids per year.

Hanningfield sludge reed bed system

Hanningfield Water Treatment Work is supplied with raw water from Hanningfield Reservoir (354 ha) with a water production of 150 million litres/day for 1.5 million people. The Hanningfield (England) Sludge Reed Bed System is a new system treating water works sludge. The use of reed bed systems not only reduces the capital and operating cost, but also provides the site with an environmentally-friendly operational area. Therefore, 6 trials bed (20 m^2 each) have been monitored (2008 – 2010) to examine the dewatering processes of the liquid sludge produced from the water treatment process, which includes treatment with iron sulphate to help dirt particles to coagulate. It is possible to get the vegetation to grow in ferric sludge, where the pH was measured to 7.7. It has not been necessary to use fertilizer. The influence of the loading programs (15-50 kg DS/m^2/year) was tested. It is possible to drain and treat ferric sludge (approximately 300000 mg Fe/kg DS). Generally the dewatering profile is a peak with a maximum over 0.010 – 0.025 l/sec/m^2. The times for dewatering of 6-12 m^3 are approximately 15 hours and over 90 % of the load is dewatered in that period. Even for the basins which had been loaded with 12 m^3 each day for 4-6 days. The dry solid (0.13 - 0.20 %) in the sludge has been concentrated approximately 200 times. The dewatering phase results in ferric sludge with 30-40% dry solid which cracks up very quickly. In spite of the different loading programs, volume reduction is very high at over 99 %. Based on a total load of 1275 tons/year, the test results lead to a design with a loading rate of 30 kg DS/m^2/year, a red bed area of 42500 m^2, and 16 parallel basins.

Conclusion

This paper presents experience and know-how from a 24-year period (1988-2012), primarily with references from Denmark. The accumulation of knowledge, guidelines for dimensioning and operations, and descriptions are based on experience from more than 10 sludge reed bed systems, mainly loaded with activated sludge residue. The Sludge Treatment Reed Bed System is a long-term sludge solution, and the systems are built to treat sludge for an average operative period of 10 years. Experience shows that operation is reliable and flexible, with very low operating costs, low energy consumption, no use of chemicals (polymers) for dewatering, an improved working environment and the freeing-up of waste water treatment capacity. The basins in Helsinge sludge reed bed system have, since 1998, been subjected to an average loading rate of approx. 55 tons DS per year, resulting in an average area-specific loading rate of 55-64 kg DS/m^2/year. The sludge residue height in relation to time and area-specific loading rate increased from 1998 to 2008 was approximately 1.60 m. or approximately 0.16 m per year. It has been possible to maintain full capacity during emptying because the basins are re-established after emptying with sufficient regeneration of vegetation.

It has thus not been necessary to re-plant basins. Experience shows that good mineralisation of hazardous organic compounds, good reduction of pathogenic microorganisms and a final dry solids content of 20 - 40% can be achieved. With respect to heavy metals, hazardous organic compounds and pathogen removal 10 years of treatment make it possible to recycle the biosolids on agricultural land.

References

De Maeseneer, J.L. (1997): Constructed wetland for sludge dewatering. Water Sci Technol 35(5), 279-285.

Giraldi, D., Masciandaro, G., Peruzzi, E., Bianchi, V., Peruzzi, P., Ceccanti, B., Iannelli, R. (2008): Hydraulic and biochemical analysis on real scale sludge consolidation reed beds in Tuscany (Italy). In: Billore S., Dass P., Vymazal J. (Eds.): Proceedings of the „11th International Conference on Wetland Systems for Water Pollution Control“, 1-7 November 2008, Indore, India, pp.634-639.

Liénard, A., Duchène, Ph., Gorini, D. (1995): A study of activated sludge dewatering in experimental reed-planted or unplanted sludge drying beds. Water Sci Technol 32(3), 251-261.

Nielsen, S. (2003a): Sludge Drying Reed Beds. Water Sci Technol 48(5), 101-109.

Nielsen, S. (2003b). Helsinge Sludge Reed Bed System – Reduction of Pathogenic Microorganisms. In: Dias, V., Vymazal, J. (Eds.): Proceedings of the „10th International Conference on Wetland Systems for Water Pollution Control“, 23-29 September 2006, Lisbon, Portugal, pp.1785-1794.

Nielsen, S. (2005). Mineralization of hazardous organic compounds in a sludge reed bed and sludge storage. Water Sci Technol 51(9), 109-117.

Nielsen, S. (2007). Helsinge sludge reed beds systems: reduction of pathogenic microorganisms. Water Sci Technol 56(3), 175-182.

Nielsen, S. (2008). Sludge treatment and drying reed bed systems 20 years of experience. In: Proceedings of the European Conference on Sludge Management, Liège, Belgium.

Obarska-Pempkowiak, H., Tuszynska, A., Sobocinski, Z. (2003). Polish experience with sewage sludge dewatering in reed systems. Water Sci Technol 48(5), 111 117.

Pempkowiak, J., Obarska-Pempkowiak, H. (2002). Long-term changes in sewage sludge stored in a reed bed. Sci Total Environ 297, 59-65.

Peruzzi, E., Macci, C., Doni, S., Masciandaro, G., Peruzzi, P., Aiello, M., Caccianti, B. (2007). Wetland cane (*Phragmites australis*) for sewage sludge stabilization. In: Borin, M., Bacelle, S. (Eds.): Proceedings of the International Conference on Multi Functions of Wetland Systems, 26-29 june 2007, Padova, Italy, pp.78-81.

Troesch, S., Liènard, A., Molle, P., Merlin, G., Esser, D. (2008a). Treatment of septage in sludge drying reed beds: a case study on pilot-scale beds. In: Dias, V., Vymazal, J. (Eds.): Proceedings of the „10th International Conference on Wetland Systems for Water Pollution Control“, 23-29 September 2006, Lisbon, Portugal, pp.24-34.

Troesch, S., Liènard, A., Molle, P., Merlin, G., Esser, D. (2008b). Sludge drying reed beds: a full and pilot-scales study for activated sludge treatment. In: Dias, V., Vymazal, J. (Eds.): Proceedings of the „10th International Conference on Wetland Systems for Water Pollution Control“, 23-29 September 2006, Lisbon, Portugal, pp.218-225.

Uggetti, E., Llorens, E., Pedescoll, A., Ferrer, I., Castellnou, R., García, J. (2009a). Sludge dewatering and stabilization in drying reed beds: characterization of three full-scale systems in Catalonia, Spain. Biores Technol 100, 3882-3890.

Uggetti, E., Llorens, E., Pedescoll, A., Ferrer, I., Castellnou, R., García, J. (2009b). Sludge drying reed beds: a case study. Journal of Residuals Science and Technology 6(1), 57-59.

Zwara, W., Obarska-Pempkowiak, H., (2000). Polish experience with sewage sludge utilization in reed beds. Water Sci Technol 41(1), 65-68.

Names: Steen Nielsen
Organisation: Orbicon A/S
Town, Country: Roskilde, Denmark
eMail: smni@orbicon.dk